

Drifter Motion Planning for Optimal Surveillance of the Ocean (DRIMPOS)

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LONG-TERM GOALS

In recent years substantial progress, much of it resulting directly from ONR funding initiatives, has been made in understanding fundamental features of transport and mixing in oceans using methods derived from dynamical systems theory. The purpose of the current collaborative research is to extend these methods to the design of control algorithms for Drifter Motion Planning for Optimal Surveillance of the Ocean (DRIMPOS). This effort is a direct attempt to transition Lagrangian based dynamical systems methods from diagnostic, postdictive tools to essential and active components in the design of oceanographic and naval observing systems. The specific goals of the research project include the development of flow-based control algorithms for drifting autonomous sensing systems.

OBJECTIVES

Funding for this effort arrived in June of F07. Objectives for this limited period were restricted to establishing tasks and goals for the collaborative effort involving three institutions and PIs: Poje at the City University of New York, CSI; Mezic at University of California, Santa Barbara; Schwartz at NRL, Washington DC. This has included hiring post-doctoral and graduate assistants at UCSB and NRL and the initiation of technology and data transfer between CUNY and UCSB. A kick-off meeting of PIs and associated researchers is planned for this November.

APPROACH

Problems of optimal ocean surveillance for a variety of measurement purposes present critical challenges to the current state of the art in drifter motion design. Autonomous vehicles used for such surveillance feature limited actuator abilities due to energy constraints and are thus subject to drift dictated by ocean currents. This drift is of complicated nature: the velocity fields in the ocean, even at large scales, are aperiodic in time and have complex spatial features. When measured in-situ or computed from numerical models, these fields are only known on a grid, thus prediction and control of drifter motion require coping with uncertainty induced by interpolation off the grid. In coastal regions these spatial features are three-dimensional, adding complexity to the picture. The drifters can carry sensors, indicating the possibility of feedback control for motion design. However, relaying sensor information back to the controller via wireless communications requires a non-trivial expenditure of energy. There are several objectives of interest in motion design. One is to maintain the surveillance vehicle in a pre-determined box for maximal extent of time with a limited energy expenditure (the localization problem). The second is to achieve optimal coverage of a certain ocean volume while staying within that volume (the coverage problem). And the third is to assign N vehicles to a volume

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and design their cooperative motion to simultaneously achieve localization and optimal coverage (the networked search problem).

Initially, we concentrate on the first aspect - algorithms to control autonomous sensors to maximize station keeping in a bounded domain. Our approach to the division of labor within the collaboration for the preliminary period is the following: Mezic and co-workers at UCSB have begun investigating the development of flow-based Lagrangian control schema in simplified flow fields. The approach is based on actuating control to climb gradients in the *exit-time* function, $E(\mathbf{x}, t; D)$, which is simply the amount of time a Lagrangian particle located at position \mathbf{x} at time t spends inside the fixed domain D . Schwartz and co-workers have begun to analyze realistic dynamical models of autonomous gliders for use in a control setting. Poje has begun preliminary analyses of $E(\mathbf{x}, t; D)$ in the context of high resolution NCOM simulations of the Adriatic.

WORK COMPLETED

The division of labor and coordination of research goals among the participating institutions has been established. Preliminary results have shown the *exit-time* based control scheme for station keeping to be both effective and efficient in the context of simple flow fields. Analysis of NCOM model output has produced $E(\mathbf{x}, t; D)$ fields indicative of the level of spatial and temporal variations one might expect to encounter in representative ocean (sub)-mesoscale flow fields. Transfer of numerical tools and data sets between UCSB and CUNY has been initiated.

RESULTS

In a preliminary effort to examine the expected behavior of the Lagrangian exit time function, $E(\mathbf{x}, t)$ in the ocean context, we have computed synthetic drifter trajectories in the NCOM model of the Adriatic described fully in Martin (2006) and previously used by Haza et al. (2007) for directed drifter launch experiments. Specifically, this preliminary study seeks to address three questions: (1) what is the expected amplitude and spatial structure of $E(\mathbf{x}, t)$ in a particular ocean flow?, (2) what is the degree of temporal variability in representative samples of $E(\mathbf{x}, t)$ and (3) how do the answers to (1) and (2) change in different structural regimes of a given flow? The purpose of the study is a preliminary determination of the feasibility of control strategies for autonomous underwater vehicles based in part on maneuvering up local $E(\mathbf{x}, t)$ gradients.

Three specific regions of the Adriatic flow are investigated using data supplied from NCOM hindcasts for August 2005. The regions, shown in Figure 1, are chosen to represent (a) the relatively slow and slowly evolving flow structures at the boundary between the northern and southern Adriatic gyres, (b) the separated flow ‘bubble’ downstream of the Gargano peninsula, (c) the complicated eddy-shedding region near the Croatian coast. In each region, a square array of 1681 synthetic drifters with 0.5km spacing is launched. Trajectories are computed for 10 days. The times to the first exit of a 15 km circle centered on the initial drifter array are calculated and the process repeated at 2-day intervals to assess temporal variability. A sample of the evolution of the computed $E(\mathbf{x}, t)$ fields for both the inter-gyre region and the Gargano recirculation zone are shown in Figure 2. In each case, there are measurable sets of initial conditions where $E(\mathbf{x}, t_0)$ exceeds the 10-day integration time. The location of such points evolves in time in accordance with the dynamics of the meso-scale eddy field. Notably, the correlation between the instantaneous velocity field at any time and $E(\mathbf{x}, t)$ computed over ten day windows is typically small. In fact, locally in both time and space, there exist regions of strong alignment between the flow field and $E(\mathbf{x}, t)$. As expected, the spatial structure of the *exit-time*

function is more uniform in the inter-gyre region than in the Gargano recirculation zone. The corresponding temporal evolution is slower. Of note, the strong influence of inertial circulations in the Adriatic interior for this time period implies, as seen in Figure 2a on Aug 9, that there are periods of time when the local flow is extremely well aligned with the $-E(x, t)$. Given the relatively slow evolution of the $E(x, t)$ map, this implies that there are local regions in time and space where the flow acts to direct particles towards regions of higher exit times.

IMPACT/APPLICATIONS

We expect that Lagrangian metrics such as *exit-time* maps derived from Naval ocean forecast models will provide the necessary flow-based information for autonomous vehicle control algorithms. Similar measures computed from NCOM Adriatic forecasts during the NATO sponsored DART05 experiment were successfully used to direct traditional drifter launches.

The next immediate steps of the UCSB/CUNY collaboration will be to extend the *exit-time* based control algorithm in development at UCSB to the time-dependent Adriatic model flow. Concurrent with that effort, analysis and comparison of differences in $E(x, t)$ for NCOM Adriatic hind and forecasts will be completed. Quantification of the sensitivity of the Lagrangian measures to Eulerian model details in this context is essential for constructing robust control schema. Operationally, any flow-based control will depend to some extent on the accuracy of short-term model forecasts of the flow.

RELATED PROJECTS

With sponsorship under ONR grant N00014-04-10192, the PI actively collaborates with Professors T. Ozgokmen and A. Griffa at the University of Miami on questions concerning Lagrangian data assimilation, optimal deployment strategies, model-data intercomparison and the sensitivity of Lagrangian Coherent Structure boundaries to model error and filtering. Under the same grant, the PI collaborates regularly with Professors A.D. Kirwan and B. Lipphardt at the University of Delaware.

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PUBLICATIONS

None.

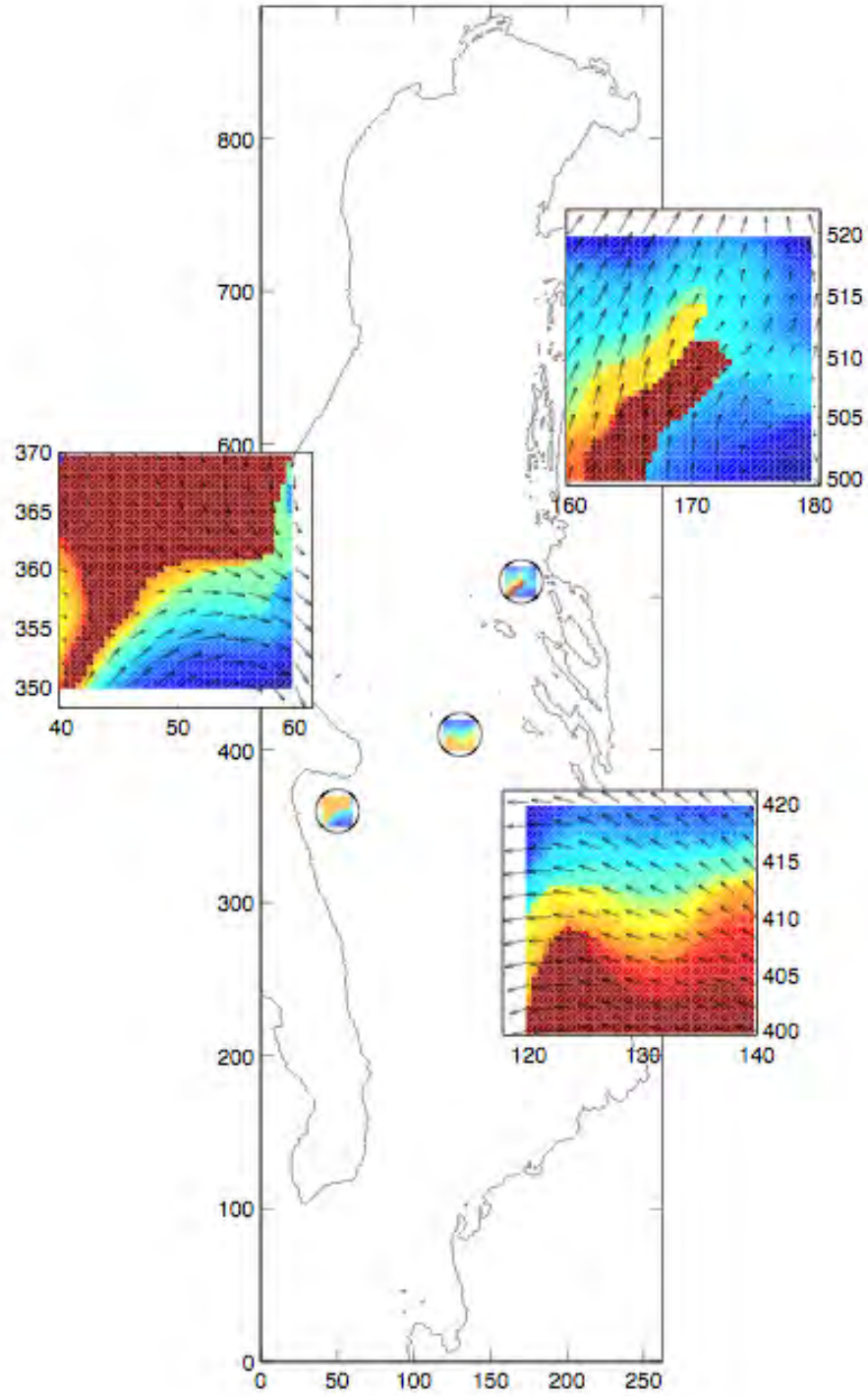


Figure 1: NCOM model domain of the Adriatic and $E(x, t)$ fields indicating the three regions analyzed. Counterclockwise from lower right: (1) the boundary region between the northern and southern Adriatic gyres, (2) the Croatia coastal flow region, (3) the recirculation bubble of the Western Adriatic Current south of the Gargano Peninsula.

The circles within the domain indicate the fixed regions for which exit times were computed.

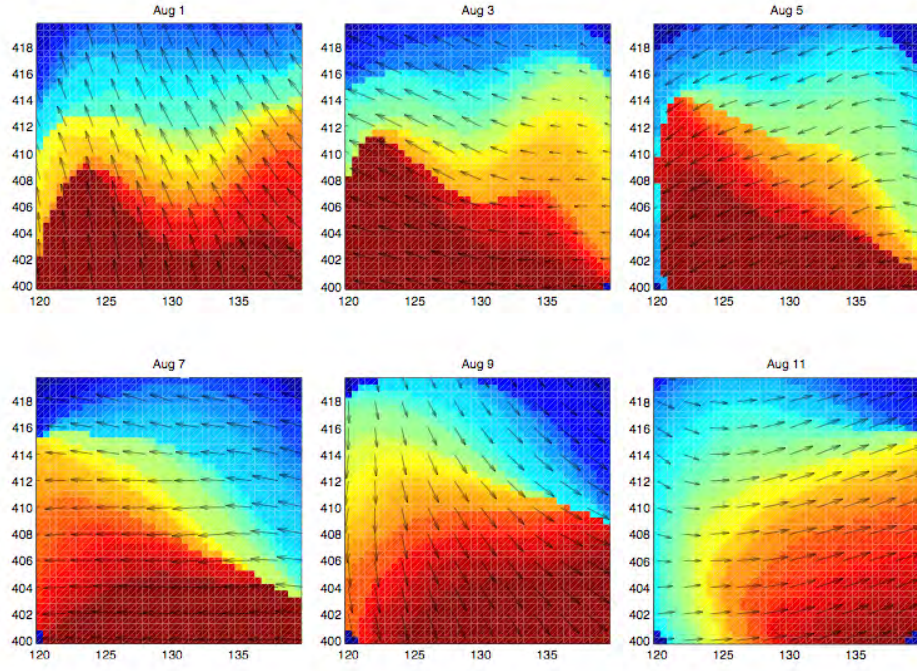


Figure 2a: The 10 day exit time function in the inter-gyre region computed every 2 days for six different initialization times. Superimposed on each is the model velocity field at the initialization time. Note the lack of correlation between gradients of $E(x,t)$ and the instantaneous Eulerian field at certain times and the strong anti-correlation of the two on Aug 9.

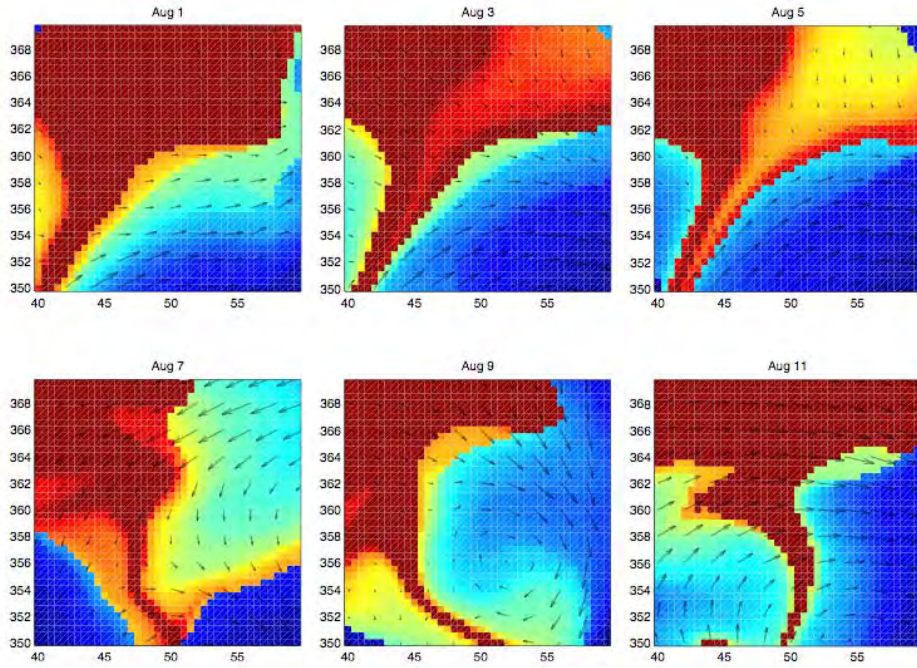


Figure 2b: The 10 day exit time function in the Gargano region computed every 2 days for six different initialization times. Superimposed on each is the model velocity field at the initialization time.